THE FORAMINIFERAL GENUS *BOLIVINOIDES* FROM THE UPPER CRETACEOUS OF THE BRITISH ISLES

by F. T. BARR

ABSTRACT. Nine species of *Bolivinoides* are described from the Upper Cretaceous (Santonian to Lower Maestrichtian) strata of the British Isles, and their stratigraphical ranges are recorded in relation to the classical megafossil zonation. Three of these species, *Bolivinoides hiltermanni*, *B. praelaevigata*, and *B. sidestrandensis*, are described as new and a lectotype is proposed for *B. decorata* (Jones). The phylogeny of various lineages of the genus *Bolivinoides* is discussed.

DURING the last fifteen years, a series of important studies has been published on the Upper Cretaceous–Lower Tertiary foraminiferal genus *Bolivinoides* Cushman. In Germany, Hiltermann (1952, 1963) and Hiltermann and Koch (1950, 1955, 1960, 1962) have published a number of valuable works demonstrating the stratigraphical value of *Bolivinoides* in strata of Santonian to Danian age. The usefulness of this group has been shown by Edgell (1954) in Australia, Reiss (1954) in the Middle East, Pożaryska (1954) in Poland, and Vassilenko (1961) in the Soviet Union. The stratigraphical ranges of many species of this rapidly evolving group appear to be almost identical over much of the world. Consequently, some lineages of *Bolivinoides* have proved to be extremely useful in intercontinental correlations within the upper part of the Upper Cretaceous.

The Upper Cretaceous Chalk of the British Isles usually contains abundant and diverse foraminiferal faunas. In strata of Santonian to Maestrichtian age, various species of *Bolivinoides* are often an important element of this fauna. A number of short publications mentioned the presence of one or more of these species in the British Upper Cretaceous, but no attempt had been made to monograph this group or to establish their usefulness in the precise dating of the Upper Cretaceous Chalk in the British Isles. Wright (1886) originally described *Bolivinoides decorata* from the Upper Campanian of Keady Hill, Northern Ireland. In a short note, Chapman (1892) described *B. strigillata* for the first time from the Santonian phosphatic chalk at Taplow in Buckinghamshire. *B. decorata* was recorded by Heron-Allen and Earland (1910) from the interior of a flint nodule found on the beach at Selsey Bill, Sussex. Williams-Mitchell (1948, p. 106, pl. 9, fig. 3, pl. 10) illustrated a specimen of *B. decorata* from southern England which he misidentified as *B. strigillata* (Chapman). In an important work on the Upper Cretaceous Foraminifera from Northern Ireland, McGugan (1957) recorded and illustrated specimens identified as *B. decorata* and *B. draco* (Marsson) from the Ballycastle Pellet Chalk. Curry (1962) recorded several species of *Bolivinoides* from submarine cores taken from the English Channel, but none of the specimens were illustrated or described. Recently, Barr and Cordey (1964) re-examined Chapman's (1892) material and proposed a lectotype for *B. strigillata*.

The purpose of the present paper is to describe the various species of *Bolivinoides* found in the British Isles and to record their stratigraphical ranges, which can be

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compared with the classical Upper Cretaceous megafossil zonation recognized in western Europe. It is hoped that this study will aid in the precise dating and correlation of the Upper Cretaceous strata of the British Isles and further our understanding of the evolution of certain lineages of the genus *Bolivinoides*.

Deposition of types. The lectotype and syntypes of *Bolivinoides decorata* (Jones) are housed in the Joseph Wright Collection in the Department of Zoology, Queen's University, Belfast, Northern Ireland. Illustrated topotype specimens of *Bolivinoides decorata australis* Edgell are located in the Commonwealth Paleontological Collection, Bureau of Mineral Resources, Canberra, Australia. All other holotypes, paratypes and hypotypes illustrated in this paper are deposited in the British Museum (Natural History), London. Additional paratypes of *B. hiltermanni*, *B. praelaevigata*, and *B. sidestrandensis* will be deposited in the foraminiferal collections of the U.S. National Museum, Washington, D.C.

Acknowledgements. I would like to thank Dr. Tom Barnard for his help in many aspects of this study; Drs. H. Hiltermann and Z. Reiss for their helpful suggestions; Miss Anne Cameron, for the loan of material from the Joseph Wright Collection; Dr. N. H. Fisher, for sending type material from Edgell's Collection; Dr. R. E. H. Reid, who furnished material from the Ballycastle Pellet Chalk and gave helpful information concerning Irish stratigraphy and the location of old foraminiferal collections in Northern Ireland; Dr. A. McGugan, who sent material from Northern Ireland; Mr. S. V. Bell for help in collecting the Norwich and Sidestrand localities; Dr. W. A. Berggren, who drew my attention to several important Russian studies; and also my wife Melza, for preparing the illustrations of foraminifera used in this paper.

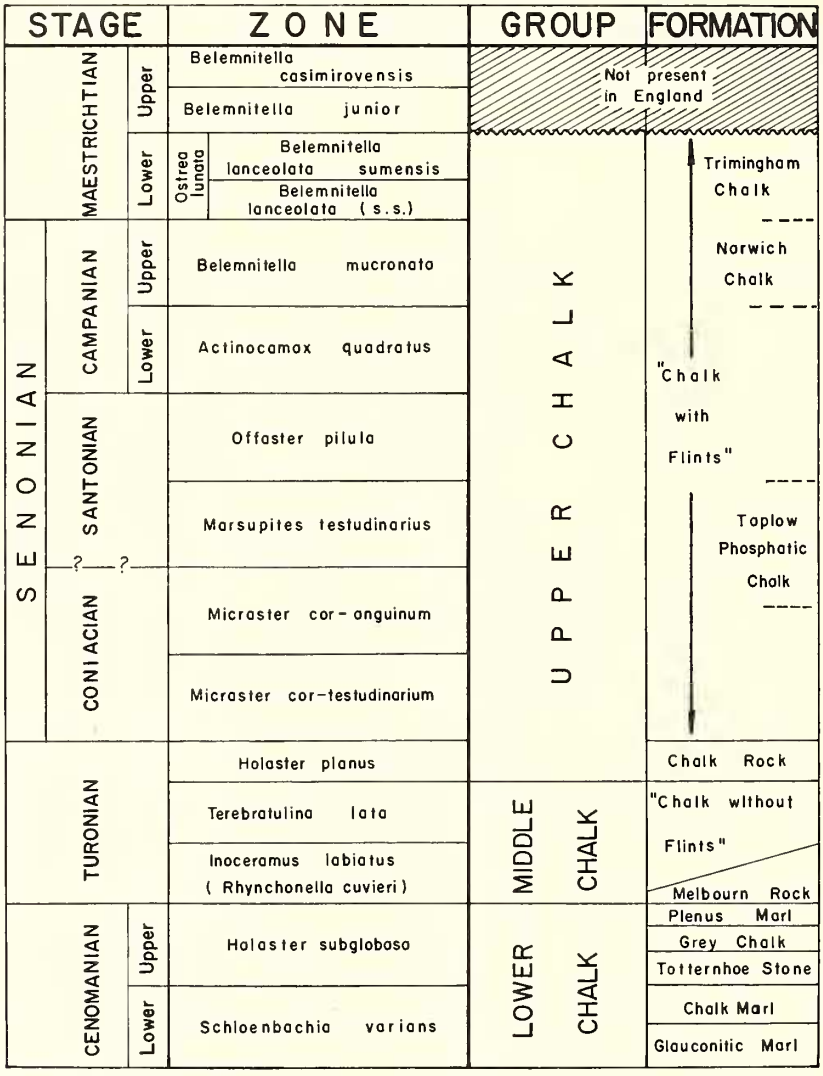
STRATIGRAPHY

The Upper Cretaceous Chalk forms many prominent outcrops in southern England and the excellently exposed sea cliff sections often represent continuous deposition from Cenomanian to Upper Campanian times. Chalk of Maestrichtian age is present only in a few small outcrops along the Norfolk coast (i.e. Trimingham, Sidestrand). Over much of southern England, Upper Campanian strata have been truncated by a Lower Tertiary unconformity. Samples used in the present study were collected from various localities in southern England, Northern Ireland and Eire. Stratigraphic sections were measured and collected at Culver Cliff, on the east coast of the Isle of Wight (see text-figs. 2, 3), and at Alum Bay, on the opposite side of the island. The stratigraphy of the Culver Cliff section has already been described (Barr 1962). Most of the sample localities had been previously dated by megafossils and placed in the classical zonation that has been used in England and parts of western continental Europe for over half a century (see text-fig. 1).

One of the earliest successful attempts to zone the Upper Cretaceous rocks of the British Isles was made by Barrois (1876). He completed a comprehensive study of the Upper Cretaceous rocks of England and Ireland and showed that it was possible to recognize the same megafossil zones in the British Isles as were established in the Upper Cretaceous of France, and that these zones could be grouped into the Cenomanian, Turonian and Senonian Stages proposed by d'Orbigny (1842, 1852). This zonation has since been modified and refined by Jukes-Browne (1904, 1912), Rowe (1908), Brydone (1914), Jeletzsky (1951), and others, but still forms the basis for the present megafossil zonation of the British Upper Cretaceous.

Maestrichtian Stage. The Maestrichtian Stage was originally proposed by Dumont (1849). Its type is section located in the E.N.C.I. Quarry at St. Pietersburg on the

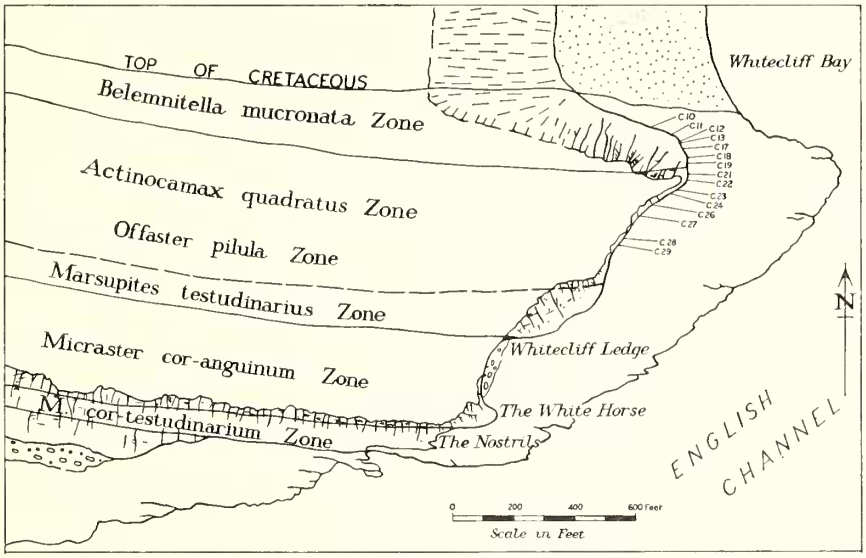
outskirts of Maastricht, Netherlands. In recent years the literature on the type section and correlation of the Maestrichtian Stage has been voluminous and sometimes contradictory. However, it is now generally accepted that the Maestrichtian Stage should be



TEXT-FIG. 1. Chart showing megafossil zonation of the Upper Cretaceous strata of the British Isles.

regarded as the uppermost Cretaceous stage, underlying the Danian Stage of Desor (1846), which is now regarded as lowermost Tertiary, and overlying either the Senonian Stage of d'Orbigny (1842, 1852) or the Campanian Stage of Coquand (1857). The Maestrichtian Stage can be subdivided on the basis of belemnites into four or more zones which can be recognized in its type area and over much of western Europe.

The only chalk of Maestrichtian age found in England is in a few small outcrops exposed along the Norfolk coast, including some large erratic blocks. Jukes-Browne (1904) and Brydone (1906, 1908) published a series of papers on these exposures in which they recognized a different fauna from that found in the Norwich Chalk or the youngest chalk found along the south coast of England. They concluded that these outcrops represented the youngest known Upper Cretaceous strata found in England. Jukes-Browne (1904) proposed the Zone of *Ostrea lunata* to include the chalk at Trimingham. Jeletzsky (1951) made a study of the belemnites from the Trimingham and



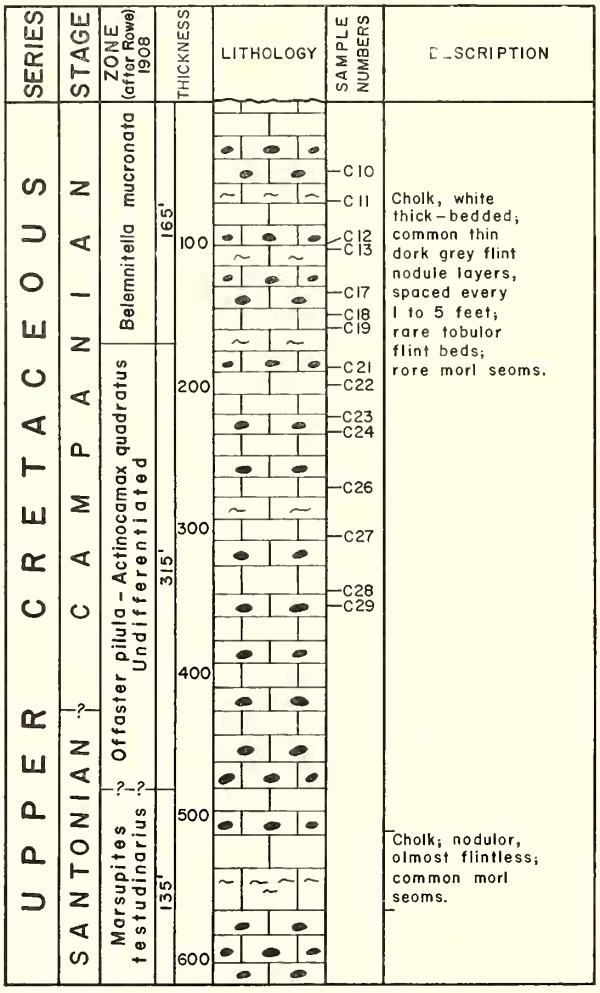
TEXT-FIG. 2. Location map of Culver Cliff on the east-central coast of the Isle of Wight showing position of samples. Zones after Rowe (1908).

Norwich Chalk and concluded that the Trimingham Chalk was Lower Maestrichtian in age and should be assigned to the *Belemnitella lanceolata* (*s.s.*) and *Belemnitella lanceolata sumensis* Zones (which are also recognized in the type area of the Maestrichtian Stage), whereas the Norwich Chalk contained *Belemnitella mucronata* and was Upper Campanian. Jukes-Browne's Zone of *Ostrea lunata* was found to be equivalent to the combined zones of *B. lanceolata* (*s.s.*) and *B. lanceolata sumensis*.

Campanian Stage. Coquand (1857, 1858), in a study of the Cretaceous stratigraphy of the northern Aquitaine Basin, proposed the erection of three stages, the Campanian, Santonian and Coniacian, which are equivalent to the Senonian Stage of d'Orbigny. The type locality of the Campanian Stage is in south-west France near Aubeterre, while the type locality of the Senonian Stage is in the Paris Basin (d'Orbigny 1842, 1852). Through the years the Campanian, Santonian, and Coniacian have been regarded as substages of the Senonian; however, over the last one or two decades, there has been a tendency to use Coquand's units as stages and to drop the broader term Senonian. Unfortunately, the type sections of these stages are not well known and the exact position of the boundaries between these stages is not always certain. This is partially

responsible for Coquand's stages not being accepted in the Gulf Coast area of the U.S.A., where the local stage names Navarro, Taylor, and Austin are in use.

The Campanian Stage is subdivided into two belemnite zones, the *Belemnitella mucronata* Zone and the *Actinocamax quadratus* Zone, which are regarded as equivalent to the



TEXT-FIG. 3. Columnar section of upper part of the Upper Chalk at Culver Cliff, Isle of Wight, showing stratigraphic position of samples.

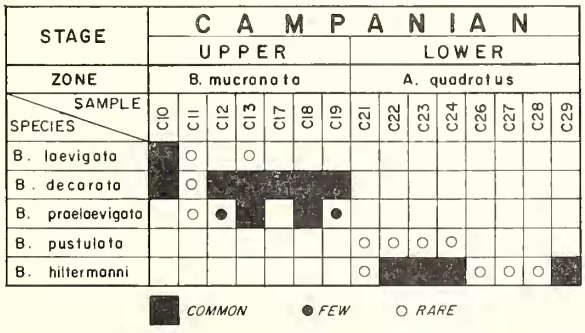
Upper and Lower Campanian respectively. Jeletzsky (1951) presented cogent reasons for placing the Maestrichtian–Campanian boundary at the top of the *B. mucronata* Zone rather than within this zone as has sometimes been done (Barnard and Banner 1953, p. 207; Curry 1962, p. 181).

Santonian Stage. The Santonian Stage was erected by Coquand (1857, 1858), with the type locality near the town of Saintes in the northern Aquitaine Basin. The limits of this

stage have not been well defined, and consequently there is considerable disagreement as to what constitutes the Lower Santonian in north-western Europe and the British Isles. In Britain, the Santonian–Coniacian contact is usually placed at the base of the *Marsupites testudinarius* Zone (Barnard and Banner 1953; Barnard 1963; Barr 1962; Curry 1962). On the other hand, many continental stratigraphers (e.g. Gignoux 1955, p. 392) include the *Micraster cor-anguinum* Zone in the Lower Santonian and place the Santonian–Coniacian contact at the base of the *M. cor-anguinum* Zone. This difference can only be resolved when the type sections of the Santonian and Coniacian Stages become better known and when exact correlations are possible between the Anglo-Paris Basins and the northern Aquitaine Basin. One must keep this difference in mind when comparing the stratigraphical ranges of fossils recorded from various parts of Europe.

PHYLOGENY

A number of papers have dealt with the phylogeny of certain species or lineages of *Bolivinoides*. The works of Hiltermann and Koch (1950), Edgell (1954), Reiss (1954), Hofker (1957, 1958*a*, 1958*b*), Vassilenko (1961), and Hiltermann (1963) have shown evolutionary development in this group to be similar in various parts of the world. Consequently, the recognition of these evolutionary sequences within the genus *Bolivinoides* can be extremely useful in the correlation and dating of Upper Cretaceous

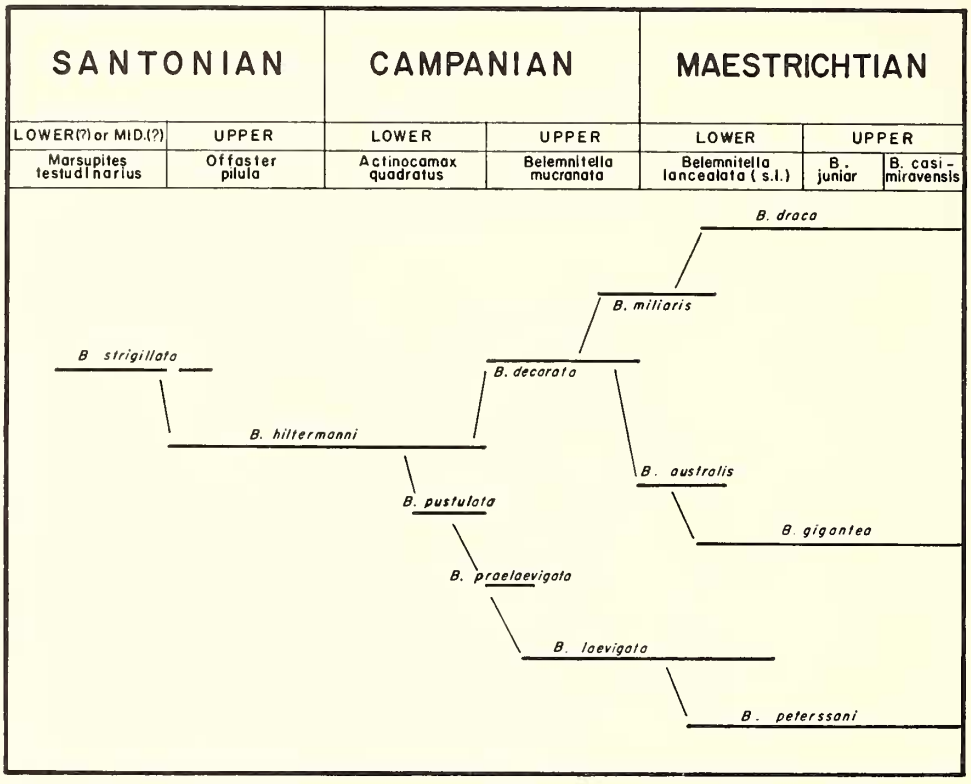


TEXT-FIG. 4. Chart showing distribution of *Bolivinoides* in the Campanian chalk at Culver Cliff, Isle of Wight.

strata. However, there is not complete agreement as to the phylogeny of all *Bolivinoides* lineages and it has been suggested (Hiltermann 1963) that subspecific differences may exist within some evolutionary lineages in different geographic provinces. The Upper Cretaceous Chalk of the British Isles provides an excellent opportunity to observe the development of some lineages of *Bolivinoides* and it is hoped that these observations will help clarify some of the phylogenetic relationships of this group.

Bolivinoides strigillata (Chapman) appears to be restricted to the *Marsupites testudinarius* Zone (Lower or Middle Santonian) and possibly the basal part of the *Offaster pilula* Zone. It is the oldest species of *Bolivinoides* recognized in the British Isles or elsewhere in the world, and from this species evolved the various lineages that are so common higher in the Upper Cretaceous strata. *B. strigillata* (*s.s.*) is usually quite rare, but the many forms which rapidly evolved from this ancestral species became increasingly abundant and diversified later in the Upper Cretaceous. The genus *Bolivinoides*

reached its acme in the Maestrichtian and survived into the Danian, but with progressively fewer individuals.



TEXT-FIG. 5. Diagram showing the stratigraphic ranges and suggested phylogeny of various species of *Bolivinoides*.

The most common lineage of *Bolivinoides* observed in the British Isles commences with *B. strigillata* and evolves through *B. hiltermanni* sp. nov., *B. decorata* (Jones) to *B. miliaris* Hiltermann and Koch. The end member of this lineage, *B. draco* (Marsson), was not found, as the Upper Maestrichtian is not present in Britain, nor was the *B. australis–B. gigantea* offshoot observed. The *B. strigillata–B. gigantea* lineage shows several progressive changes in morphology: an increase in overall size; smaller length/breadth ratios; and an increase in the number of 'ornamental' lobes on the final chambers. The evolution of *B. decorata* to *B. miliaris* to *B. draco* produces a progressively more rhomboidal or kite-shaped test and the development of medial ribs. *B. decorata* has often been regarded as evolving directly from *B. strigillata* (Hiltermann and Koch 1950; Vassilenko 1961; Hiltermann 1963). However, in the well-developed Lower Campanian section in southern England a transitional species, *B. hiltermanni* sp. nov., is found in considerable abundance. This species is intermediate in size and in strength of ornamentation between *B. strigillata* and *B. decorata*.

There is also an indication that *B. hiltermanni* is probably the ancestral species to the *B. pustulata* Reiss–*B. praelaevigata* sp. nov.–*B. laevigata* Marie–*B. peterssoni* Brotzen

lineage. *B. hiltermanni* has a thicker, less compressed test than species of the *B. pustulata–B. peterssoni* lineage; however, variants of this species found in the upper part of the *Actinocamax quadratus* Zone may represent an intermediate form between *B. hiltermanni* (*s.s.*) and *B. pustulata*, although the complete transition of forms was not observed. The *B. pustulata–praelaevigata–laevigata–peterssoni* lineage is characterized by a small compressed test with rather weakly developed ornamentation chiefly restricted to the medial part of the test.

SYSTEMATIC PALAEONTOLOGY

Order FORAMINIFERIDA
Superfamily BULIMINACEA Jones 1875
Family BOLIVINITIDAE Cushman 1927
Genus BOLIVINOIDES Cushman 1927

Type Species. Bolivinoides draco (Marsson).

Description. Test completely biserial, gradually tapering to flaring, with greatest breadth usually near apertural end, and circular or elliptical in cross section. Proloculus globular, smooth. Chambers inflated, curved, uniformly and fairly rapidly increasing in size with greatest height and thickness near longitudinal axis. Sutures often obscure, slightly curved. Aperture a slit-like or loop-shaped opening near centre of apertural face, often bordered by weakly developed lip and with internal tooth plate structure. Ornamentation usually strongly developed, consisting of lobes and knobs running perpendicular to sutures. Internal wall surface also contains semi-conical bulges. Wall calcareous, finely perforate.

Remarks. Numerous specimens of *Bolivinoides* were serially sectioned and their internal structure examined. The present study confirms many of Montanaro Gallitelli's (1957, pp. 145, 146) observations. She examined the internal structure of acid treated specimens of *Bolivinoides draco* (Marsson) and observed that the internal surface of the test had a tuberculate sculpture. The internal surface of the tests of all species sectioned in the present study contained semi-conical bulges along the base of the chambers. In species such as *B. draco* with strongly developed, but fine external ornamentation, the internal circular bulges occupy most of the chamber walls in the earliest chambers and occupy somewhat less in the final chambers. In most of the other species, however, the internal bulges are restricted to about the lower quarter of the chamber surface. The maximum breadth of the bulge is along the lower suture. These internal knobs correspond to the depressed areas between lobes on the external surface. In fact, almost all of the external 'ornamental' lobes and knobs are reflected interiorly, producing a partially corrugated test wall (see text-figs. 7, 8). These observations do not agree exactly with those of Reyment (1959, p. 13) who stated that the tuberculated wall structure seen by Montanaro Gallitelli was derived from cameral overlaps. The external sculpture, and concomitantly the internal sculpture, of *Bolivinoides* therefore appears to represent structure more fundamental than the more usual surface ornamentation of many genera, which is sometimes quite superficial.

An internal bolivine tooth plate structure was observed in *Bolivinoides*, similar to that described by Hofker (1957) and Reyment (1959).

Bolivinoides strigillata (Chapman)

Plate 34, figs. 8, 9; Plate 37, figs. 7–9

Bolivina strigillata Chapman 1892, p. 515, pl. 15, fig. 10.
Bolivinoides strigillata (Chapman); Hiltermann and Koch 1950, pp. 614–23, text-figs. 2 (1–19), 3 (1–9), 5 (10).
Bolivinoides strigillata (Chapman); Edgell 1954, pp. 70, 71, pl. 13, fig. 8; pl. 14, fig. 9.
Bolivinoides strigillatus (Chapman); Bykova 1959, table 1, fig. 1.
Bolivinoides strigillata (Chapman); Vassilenko 1961, pp. 186–8, pl. 39, figs. 7*a–c*.
Bolivinoides strigillata (Chapman); Hiltermann 1963, pp. 209, 210, pl. 1, figs. 12–14, 16, 18, 19, 24.
Bolivinoides strigillata (Chapman); Barr and Cordey 1964, pp. 308, 309, pl. 49, figs. 1–3.

Description. Test biserial, elongate, sides gradually tapering, subelliptical to oval in cross section; proloculus globular, followed by 6 to 8 pairs of indistinct, slightly inflated chambers uniformly and gradually increasing in size; sutures slightly oblique, indistinct, obscured by ornamentation; 2 or 3 weakly raised lobes on final chambers running perpendicular to sutures, ornamentation on earliest chambers less distinct, sometimes surface of early part of test smooth; aperture a slit-like opening between lobes on final chamber; wall calcareous, finely perforate; length/breadth ratio 1·7 to 2·2; breadth/thickness ratio 1·4 to 1·9; approximate average length of adult specimen 0·40 mm.

Remarks. Bolivinoides strigillata is the most primitive species known of the genus *Bolivinoides*, and the only species found in strata as old as the *Marsupites testudinarius* Zone in the British Isles. It is one of the smallest species of *Bolivinoides* and appears to be the ancestral species of several of the most common and stratigraphically important lineages of this genus (see text-fig. 5).

Chapman (1892, p. 515) originally described *B. strigillata* from the phosphatic chalk at Taplow, Buckinghamshire. Barr and Cordey (1964, p. 308) collected additional material from Taplow and re-examined Chapman's original specimens, which are deposited in the British Museum (Natural History). They redescribed *B. strigillata* and proposed a lectotype for this species from syntypic specimens in the Chapman Collection (BM P44968).

A single specimen referred to *Bolivina strigillata* Chapman by Williams-Mitchell

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EXPLANATION OF PLATE 34

All illustrations unretouched photographs.

Fig. 1. *Bolivinoides australis* Edgell. ×118. Topotype. C. Y. Creek, near Cardabia, on the west flank of Giralia Anticline, north-west Australia; Edgell's (1954) locality GC/304.

Figs. 2–6, 12. *Bolivinoides decorata* (Jones). ×118. Showing variation in test shape and ornamentation. Upper Campanian, *Belemnitella mucronata* Zone. 2, Meudon, Paris Basin; BM P45711. 3–5, 12, Alum Bay, Isle of Wight, Sample A2, 405 ft. above base of *B. mucronata* Zone. 3, BM P45712; 4, BM P45713; 5, BM P45714; 12, BM P45716. 6, Culver Cliff, Isle of Wight, Sample C10; BM P45715.

Fig. 7. *Bolivinoides laevigata* Marie. ×118. Upper Campanian, *Belemnitella mucronata* Zone, Culver Cliff, Isle of Wight; Sample C10, BM P45740.

Figs. 8, 9. *Bolivinoides strigillata* (Chapman). ×140. Topotypes. Santonian, *Marsupites testudinarius* Zone, Phosphatic Chalk, Taplow, Buckinghamshire. 8, BM P45730; 9, BM P45731.

Figs. 10, 11. *Bolivinoides sidestrandensis* sp. nov. ×118. Lower Maestrichtian, *Belemnitella lanceolata* Zone, Sidestrand, Norfolk. 10, Paratype, BM P45745; 11, Holotype, BM P45743.

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(1948, p. 106, pl. 9, fig. 3) is located in the British Museum (Natural History). Barr and Cordey (1964, p. 308) examined the Williams-Mitchell collection and found this specimen to be clearly conspecific with *Bolivinoides decorata* (Jones). Williams-Mitchell (op. cit., pl. 10) lists the stratigraphical range of '*Bolivina strigillata*' (the only species in his paper referable to the genus *Bolivinoides*) as *Marsupites testudinarius* Zone to the top of the *Belemnitella mucronata* Zone in the Upper Cretaceous strata of England. This range undoubtedly represents the combined stratigraphical occurrence of several species of *Bolivinoides*.

Occurrence. The type locality of *Bolivinoides strigillata* is a small chalk pit, Lodge Pit, on the outskirts of Taplow, Buckinghamshire. Chapman obtained his specimens from about the middle of the phosphatic band in this pit. Osborne White and Treacher (1905) placed this part of the section in the *M. testudinarius* Zone (Santonian). *B. strigillata* appears to be restricted to the *M. testudinarius* Zone in England, but may possibly occur also in the *Offaster pilula* Zone.

Edgell (1954, pp. 70, 71) recorded *B. strigillata* from the Santonian of north-western Australia. Vassilenko (1961, p. 188, 297) reported this species from the Santonian and basal Campanian of the Soviet Union.

Hiltermann (1963, p. 205) and Hiltermann and Koch (1960, p. 71) listed the stratigraphic range of *B. strigillata* in north-western Europe as Upper Santonian to Lower Campanian. This range does not agree exactly with the range observed by me for this species in England. The apparent difference in range for this species between Germany and England may be due to the following reasons:

1. The *M. testudinarius* Zone is usually considered by British stratigraphers as Lower Santonian (Barnard and Banner 1953; Curry 1962), whereas many continental stratigraphers (Gignoux 1955, p. 392) place this zone in the Middle or Upper Santonian and regard the underlying *Micraster cor-anguinum* Zone as the Lower Santonian.

2. Many specimens which were once grouped with *B. strigillata*, or considered to be transition forms between *B. strigillata* and *B. decorata*, are now placed in the newly erected species *B. hiltermanni*. Probably most of the specimens referred to *B. strigillata* from the Lower Campanian (*Actinocamax quadratus* Zone) should now be considered as *B. hiltermanni*.

Bolivinoides hiltermanni sp. nov.

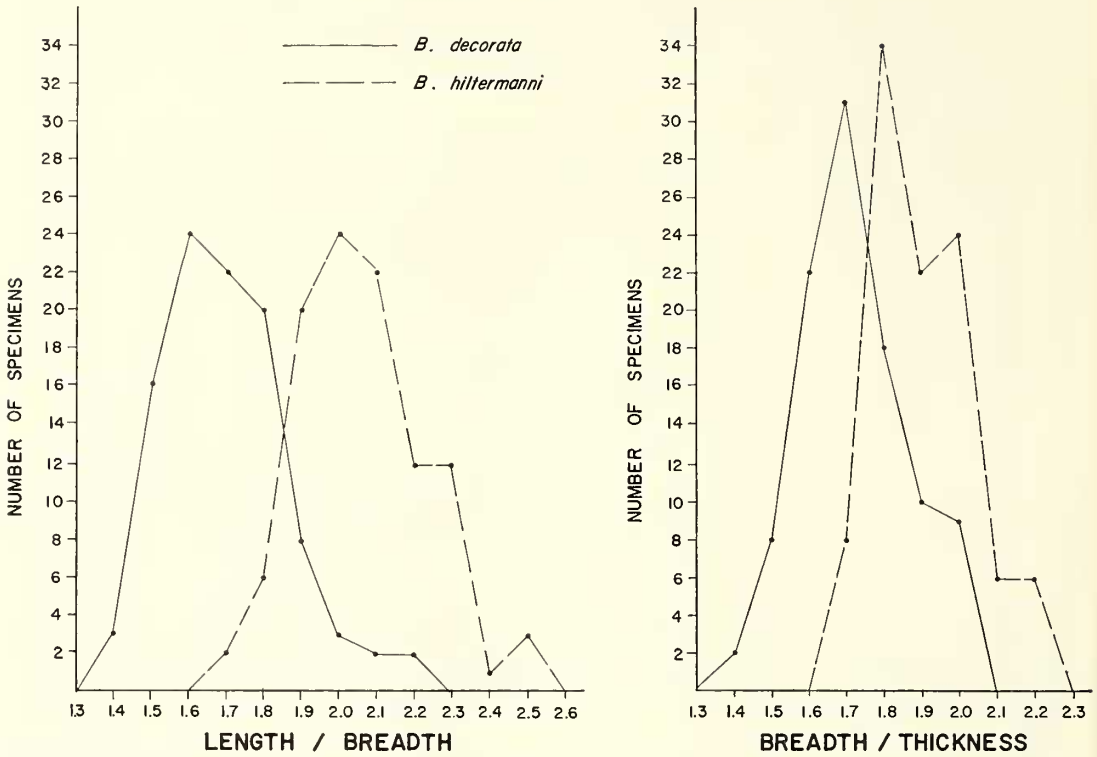
Plate 36, figs. 7, 8; Plate 37, figs. 1–3

Bolivinoides decorata (Jones) cf. *delicatula* Cushman; Edgell 1954, p. 71, pl. 13, fig. 7; pl. 14, fig. 7.

Bolivinoides sp. [transition form between *B. strigillata* (Chapman) and *B. decorata* (Jones)]; Hiltermann 1963, p. 209, pl. 1, figs. 2, 3, 7–9.

Description. Test completely biserial, elongate, tapering, greatest breadth and thickness near apertural end, initial end acutely rounded, apertural end more broadly rounded, elliptical in cross section; proloculus globular, succeeded by 7 to 8 pairs of tapering chambers uniformly and fairly rapidly increasing in size; sutures oblique, slightly curved, partially obscured by ornamentation; aperture a slit-like or loop-shaped opening located near centre of apertural face, sometimes bordered by weakly raised indistinct

lip, and with internal bolivine tooth plate structure; 2 to 4, usually 3 distinct lobes on final 2 or 3 pairs of chambers running perpendicular to sutures, less distinct lobes and knobs present on earlier chambers and usually surface of earliest 1 to 3 pairs of chambers



TEXT-FIG. 6. Diagrams showing comparison of length/breadth and breadth/thickness ratios of 100 specimens of *Bolivinoides decorata* (Jones) and 100 specimens of *B. hiltermanni* sp. nov. All specimens of *B. decorata* are from sample C10, *Belemnitella mucronata* Zone, Culver Cliff. All specimens of *B. hiltermanni* are from sample C29, *Actinocamax quadratus* Zone, Culver Cliff.

smooth; internal surface of chamber walls contains semi-conical knobs along top of suture, corresponding to depressed areas between lobes on external surface; proloculus smooth; wall very finely perforate; length/breadth ratio 1·7 to 2·5, most commonly

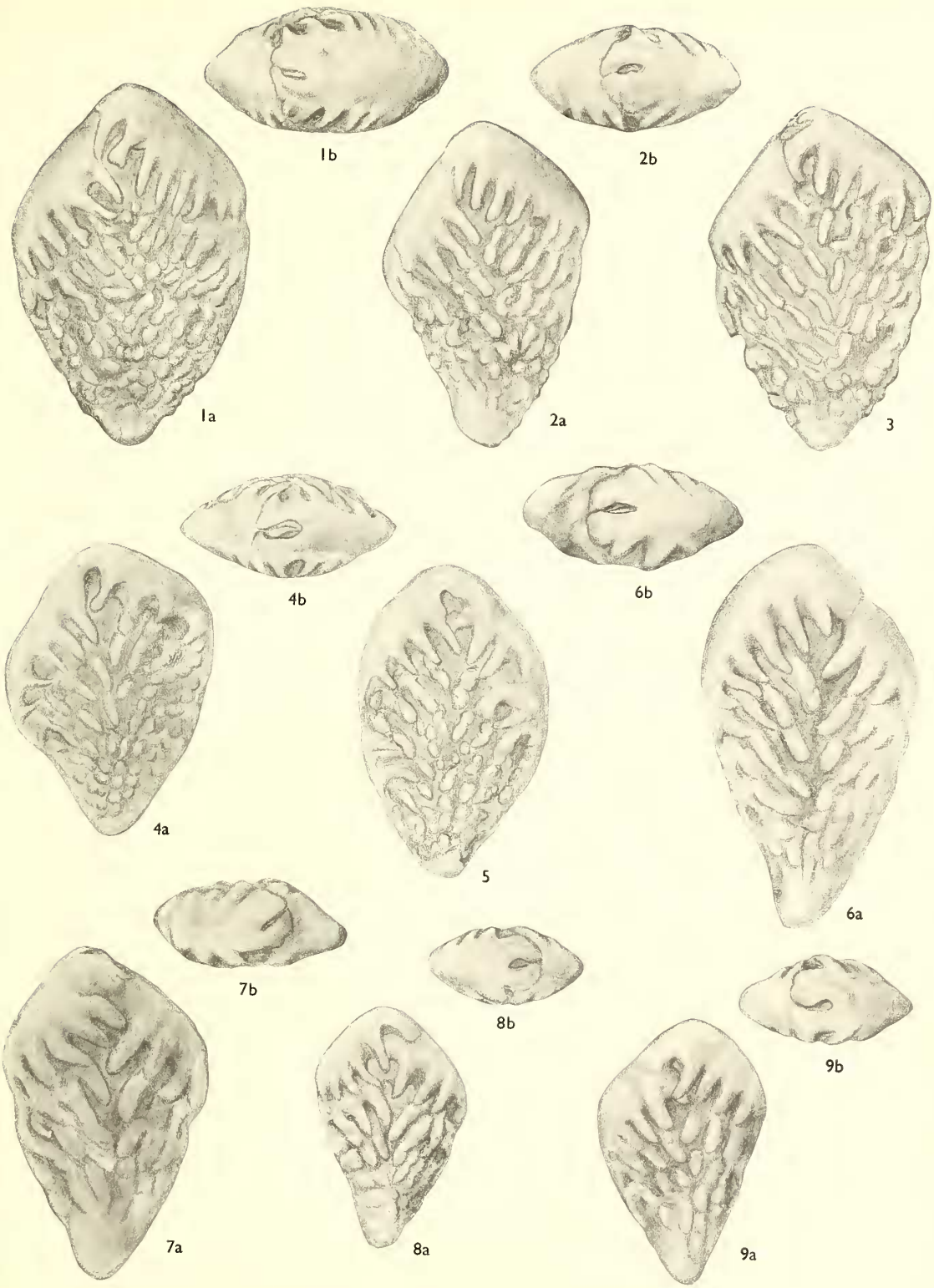
EXPLANATION OF PLATE 35

All illustrations shaded camera lucida drawings. *a* = side view; *b* = terminal view.

Figs. 1–3. *Bolivinoides australis* Edgell. ×90. Topotypes. C. Y. Creek, near Cardabia, on the west flank of Giralia Anticline, north-west Australia; Edgell's (1954) locality GC/304.

Figs. 4, 5. *Bolivinoides miliaris* Hiltermann and Koch. ×95. Ballycastle Pellet Chalk, west side Ballycastle Harbour, Northern Ireland. 4, BM P45722; 5, BM P45723.

Figs. 6–9. *Bolivinoides decorata* (Jones). ×95. Upper Campanian, *Belemnitella mucronata* Zone. 6, 7, Culver Cliff, Isle of Wight, Sample C10; BM P45718, P45719. 8, Leicester Lime Co. Quarry, Drayton, Norfolk; BM P45717. 9, Alum Bay, Isle of Wight, 405 ft. above base of *B. mucronata* Zone, Sample A2; BM P45720.



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1·9 to 2·3; breadth/thickness ratio 1·7 to 2·2; approximate average length of adult specimen 0·50 mm.

Dimensions of holotype (BM P45724). Length 0·55 mm.; maximum breadth 0·25 mm.; maximum thickness 0·14 mm.

Remarks. B. hiltermanni represents the transition form between *B. strigillata* (Chapman) and *B. decorata* (Jones). Nevertheless, *B. hiltermanni* is quite distinct from both of these species; its lower boundary with *B. strigillata* and its upper boundary with *B. decorata* are usually sharply defined, and the transition between species takes place over a relatively short stratigraphic interval. *B. hiltermanni* is distinguished from *B. strigillata* by its: (1) larger size; (2) more elliptical cross section; (3) more rapidly tapering test; (4) more broadly rounded apertural end; and (5) usually having more ornamental lobes on its final chambers. *B. hiltermanni* differs from *B. decorata* by its: (1) smaller size; (2) less flaring test; (3) larger length/breadth ratio (usually 1·9 to 2·3 compared with 1·5 to 1·8 most usual for *B. decorata*, see text-fig. 6); (4) less distinct ornamentation, especially on the early part of the test; and (5) fewer ornamental lobes on the final chambers (most often 3 compared with the usual 4 or 5 for *B. decorata*).

B. hiltermanni is also closely related to *B. pustulata* Reiss, but is usually larger and has a more elliptical, less compressed end view. Furthermore, the ornamentation of *B. pustulata* is not as strongly developed and tends to be restricted to the medial part of the test. In the upper part of the *Actinocamax quadratus* Zone (upper part of the Lower Campanian) variants of *B. hiltermanni* become quite similar to Reiss's species. It is suggested that *B. hiltermanni* gave rise to *B. pustulata* during the middle part of the *A. quadratus* Zone. *B. hiltermanni* continued until the base of the *B. mucronata* Zone, at which time it gave rise to *B. decorata*, whereas *B. pustulata* gave rise to the *B. praelaevigata–laevigata* lineage near the beginning of the Upper Campanian.

B. hiltermanni is named in honour of Dr. Heinrich Hiltermann of Hannover, in recognition of his work on the genus *Bolivinoides*.

Occurrence. B. hiltermanni occurs in abundance throughout the *A. quadratus* Zone and more rarely in the *O. pilula* Zone in southern England. Although this species is found in abundance in the uppermost *A. quadratus* Zone, it does not survive into the *B. mucronata* Zone. The *A. quadratus* Zone–*B. mucronata* Zone (Lower Campanian–Upper Campanian) contact in southern England can be located with some accuracy at the stratigraphic position where *B. hiltermanni* is replaced by *B. decorata* (*s.s.*).

Bolivinoides decorata (Jones)

Plate 34, figs. 2–6, 12; Plate 35, figs. 6–9; Plate 36, figs. 1–5

Bolivina decorata Jones (*in* Wright 1875), pp. 87, 96, 97 (list only).
Bolivina decorata Jones (*in* Wright 1886), p. 330, pl. 27, figs. 7, 8.
Bolivina decorata Jones; Heron-Allen and Earland 1910, pl. 7, figs. 1, 2.
Bolivina decorata Jones; Macfadyen 1932, pl. 35, fig. 20.
Bolivinoides decorata (Jones); Dain 1934, pp. 33, 34, pl. 3, fig. 34.
Bolivinoides decorata (Jones); Marie 1941, p. 188, pl. 29, fig. 279.
Bolivina strigillata Chapman (*partim*); Williams-Mitchell 1948, p. 106, pl. 9, figs. 3*a*, *b*.
Bolivinoides decorata decorata (Jones); Hiltermann and Koch 1950, pp. 606–10, text-figs. 2–4, nos. 17–25, 27–31, 35–38, 42–45.

Bolivinoides decorata decorata (Jones); Hagn 1953, p. 74, pl. 6, fig. 22.
Bolivinoides decorata decorata (Jones); Reiss 1954, p. 155, pl. 28, figs. 5–8.
Bolivinoides decorata decorata (Jones); Hiltermann and Koch 1955, p. 365, pl. 28, fig. 4.
Bolivinoides decoratus decoratus (Jones); McGugan 1957, p. 339, pl. 32, figs. 10–13, 15 (*non* fig. 14).
Bolivinoides decorata decorata (Jones); Bieda 1958, pp. 32, 33, text–figs. 6*a–c*.
Bolivinoides regularis Reiss; Bieda 1958, pp. 36–38, text-figs. 9*a–c*.
Bolivinoides decorata decorata (Jones); Witwicka 1958, pp. 198, 199, pl. 9, figs. 9*a, b*.
Bolivinoides decoratus decorata (Jones); Bykova 1959, table 1, fig. 2.
Bolivinoides decoratus (Jones); Akimets 1961, pp. 188, 189, pl. 18, figs. 17, 18.
Bolivinoides decoratus decorata (Jones); Vassilenko 1961, pp. 189–90, pl. 39, figs. 8–10.
Bolivinoides decoratus decoratus (Jones); Hiltermann and Koch 1962, p. 315, table 19, pl. 46, fig. 7.
Bolivinoides decoratus (Jones); Kaptarenko-Chernousova *et al.* 1963, p. 111, pl. 25, fig. 4.

Description. Test biserial, pear-shaped in outline, elliptical in cross section; proloculus globular, succeeded by 8 to 9 pairs of slightly inflated, tapering chambers uniformly and rapidly increasing in size; sutures oblique, slightly curved, mostly obscured by ornamentation; aperture a slit-like or loop-shaped opening located near centre of apertural face, sometimes bordered by slightly raised lip and with internal tooth plate structure; 3 to 6 thick distinct lobes on final chamber running perpendicular to sutures, lobes on inner portion of chambers slightly thicker and more distinct than outer lobes, sometimes giving suggestion of 2 weakly defined medial ribs, ornamentation on earliest 1 to 3 pairs of chambers less distinct consisting of weakly raised lobes or knobs, often surface of earliest chambers smooth; proloculus smooth; wall calcareous, finely perforate; length/breadth ratio 1·4 to 2·2, most commonly 1·5 to 1·8; breadth/thickness ratio 1·4 to 2·0, most commonly 1·6 to 1·9; approximate average length of adult specimen 0·58 mm.

Dimensions of lectotype. Length 0·53 mm.; maximum breadth 0·34 mm.; maximum thickness 0·17 mm.

Remarks. In a short paper on some Upper Cretaceous Foraminifera collected from the chalk at Keady Hill, County Derry, Northern Ireland, Wright (1886, p. 330, pl. 27, figs. 7, 8) published the original description and illustrations of *Bolivina decorata*. However, this name had been used previously by T. Rupert Jones in unpublished work, and therefore Wright credited Jones with authorship of *Bolivina decorata*, even though this species was originally described in Wright's paper from material collected by Wright.

In Wright's collection of Foraminifera located in the museum of the Zoology Department, The Queen's University, Belfast, Northern Ireland, there is a small circular pillbox,

EXPLANATION OF PLATE 36

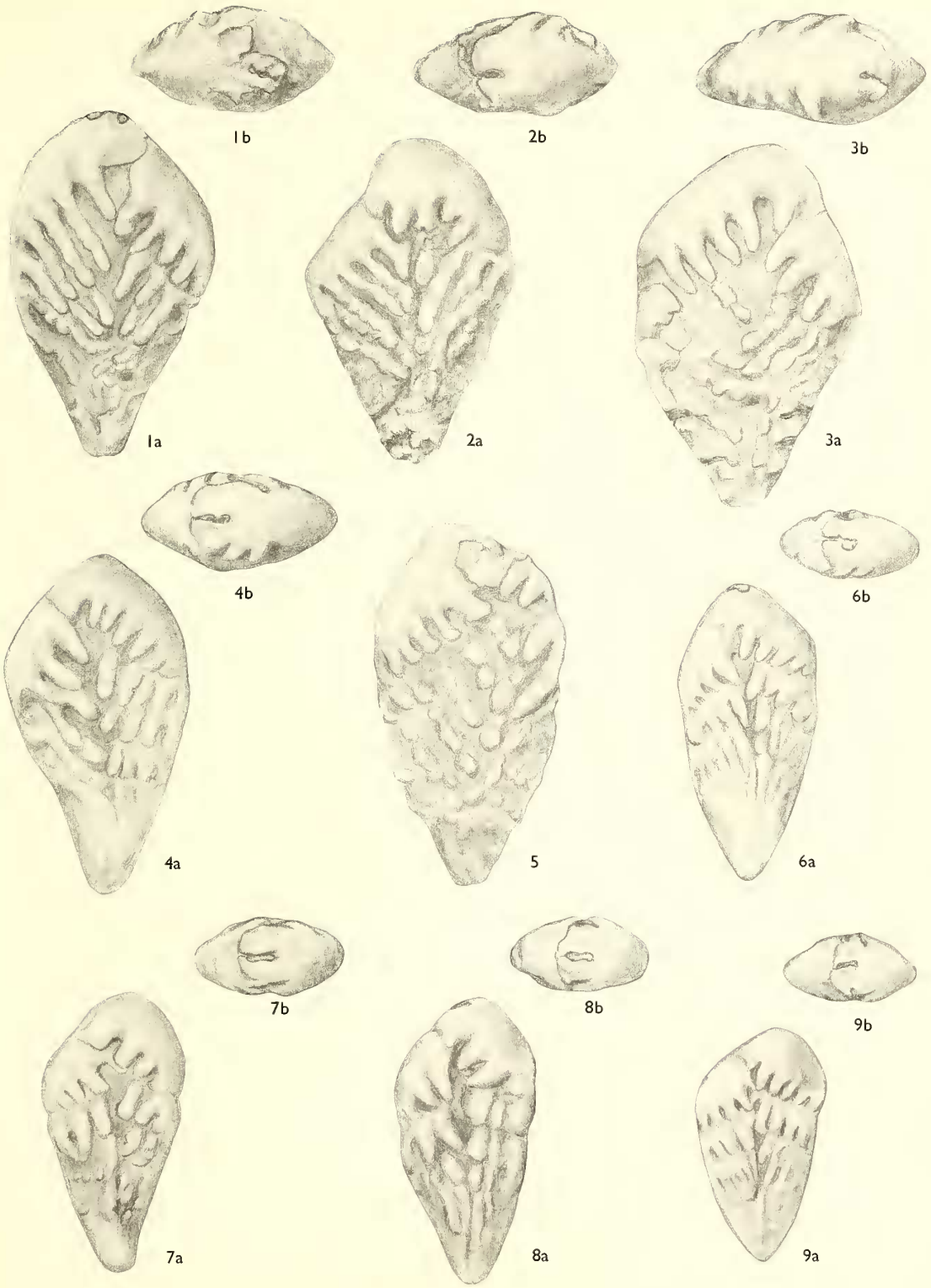
All illustrations shaded camera lucida drawings. *a* = side view; *b* = terminal view.

Figs. 1–3, 5. *Bolivinoides decorata* (Jones). ×100. Syntypic specimens from Joseph Wright Collection. 1, Lectotype. 3, 5, Specimens with badly worn surface. Upper Campanian, *Belemnitella mucronata* Zone, Keady Hill, County Derry, Northern Ireland.

Fig. 4. *Bolivinoides decorata* (Jones). ×90. Upper Campanian, *B. mucronata* Zone, Culver Cliff, Isle of Wight, Sample C10; BM P45721.

Figs. 6, 9. *Bolivinoides sidestrandensis* sp. nov. ×95. Paratypes. Lower Maestrichtian, *Belemnitella lanceolata* Zone, Sidestrand, Norfolk. 6, BM P45744; 9, BM P45746.

Figs. 7, 8. *Bolivinoides hiltermanni* sp. nov. ×95. Paratypes. Lower Campanian, *Actinocamax quadratus* Zone, Culver Cliff, Isle of Wight. 7, Sample C28, BM P45727; 8, Sample C29, BM P45726.



BARR, Upper Cretaceous *Bolivinoides*

with celluloid cover, containing nine specimens of *Bolivinoides*, and is labelled as follows: *Bolivina decorata*, Chalk powder, Keady Hill, Co. Derry 109.

No other specimens of *Bolivinoides decorata* have been found which might be regarded as primary type material for this species. These specimens from the Wright Collection are probably those originally described as *Bolivina decorata* Jones and are here regarded as syntypes. Six of these specimens are broken or badly damaged and the remaining three specimens are worn to varying degrees. Nevertheless, several of these specimens are well enough preserved to show the morphology necessary in understanding the species. A single specimen which appears to be very similar to Wright's original illustration has been isolated from the syntypic series and is designated the *lectotype* of *Bolivina decorata* (here figured Pl. 36, figs. 1*a*, *b*). Three other specimens from this syntypic series are also illustrated (Pl. 36, figs. 2, 3, 5).

TEXT-FIG. 7. Terminal view of small specimen of *Bolivinoides decorata* (Jones) with final chamber mostly broken away exposing corrugated nature of lower part of chamber wall. This view shows that the external 'ornamental' lobes are formed by folds in the chamber wall rather than by a thickening of the test wall.

Edgell (1954, pp. 71, 72) described a new subspecies of *Bolivinoides* from Australia which he named *B. decorata* (Jones) *australis*. It is distinguished from *B. decorata* (*s.s.*) by: (1) having a smaller length/breadth ratio; (2) having more ornamental lobes on the final chambers (5–7 on the final chamber compared with 3–6 for *B. decorata s.s.*); (3) possibly being more commonly ornamented near its initial end; and (4) sometimes having a more rhomboidal outline.

Ten topotypic specimens of *B. decorata australis* from C. Y. Creek, west flank of Giralia Anticline, north-west Australia, have been kindly loaned to me for examination by N. H. Fischer, Bureau of Mineral Resources, Canberra, Australia. Four of these specimens are here illustrated for comparison with *B. decorata s.s.* (Pl. 34, fig. 1; Pl. 35, figs. 1–3). These specimens show *B. decorata australis* to be quite distinct from *B. decorata s.s.* and to be closer morphologically to *B. gigantea* Hiltermann and Koch. Possibly *B. australis* might best be considered a subspecies of *B. gigantea* or even synonymous with this species. Nevertheless, although it may be difficult to consistently distinguish *B. decorata australis* from *B. gigantea*, it appears to represent a transitional form between *B. decorata* and *B. gigantea*.

The evolution of *B. decorata* to *B. australis* takes place in Western Europe and North Africa in the earliest Maestrichtian (at the beginning of the *Belemnitella lanceolata* Zone). Specimens of *B. decorata* become increasingly similar to *B. australis* in latest Campanian times. The type specimens of *B. decorata* from Keady Hill are probably from the upper part of the *B. mucronata* Zone and, consequently, two or three of the specimens of *B. decorata* from the Wright Collection represent rather advanced forms of this species.

Specimens referred to *Bolivina decorata* Jones by Heron-Allen and Earland (1910, p. 409, pl. 7, figs. 1, 2) are located in the British Museum (Natural History). These specimens have been re-examined and were found to be clearly conspecific with the type for *Bolivinoides decorata*. These specimens are from chalk meal from the interior of a cavernous flint nodule found on the beach at Selsey Bill, Sussex. The presence of *B. decorata* in the fauna from this flint nodule would strongly suggest that the nodule was originally from the *B. mucronata* Zone.

Occurrence. *B. decorata* occurs in abundance throughout the *B. mucronata* Zone in southern England and appears to be restricted to this zone. The type locality for *B. decorata* is at Keady Hill, County Derry, Northern Ireland, which is probably in the upper part of the *B. mucronata* Zone. Wright (1875, pp. 96, 97) also recorded this species from a number of other Upper Cretaceous localities in Northern Ireland.

McGugan (1957, p. 339, pl. 32, figs. 10–15) recorded *B. decorata* from the Ballycastle Pellet Chalk of Northern Ireland. R. E. H. Reid, Queen's University, Belfast, has kindly sent me material from the Ballycastle Pellet Chalk from the main exposure on the west side of Ballycastle Harbour. This material contained a number of specimens of *B. decorata* along with rarer specimens of *B. sidestrandensis* sp. nov. and *B. miliaris* Hiltermann and Koch. All specimens of *Bolivinoides* from this material were worn to varying degrees. The benthonic fauna contained a mixture of Campanian and Maestrichtian species and represents largely, if not entirely, a derived fauna. McGugan (op. cit., p. 33) stated that the character of the exposures of the Ballycastle Pellet Chalk suggested deposition of this formation in some kind of channel in the top of the underlying Upper Cretaceous Chalk. R. E. H. Reid informs me that the principal exposure of the Ballycastle Pellet Chalk contains blocks of Tertiary basalt. It appears that the Ballycastle Pellet Chalk was derived by Tertiary erosion of an Upper Cretaceous surface (cf. Charlesworth 1963, p. 369) and the specimens of *Bolivinoides* found in this formation have also been derived from this nearby Upper Cretaceous Chalk.

I have found *B. decorata* in the newly discovered Ballydeenlea Chalk of County Kerry, Ireland (Walsh 1960). The presence of this species along with the rest of the fauna indicates that the Ballydeenlea Chalk is Campanian in age, not Middle Chalk (Turonian), as had previously been suggested (Walsh 1960, p. 113). A description of the foraminiferal fauna from this formation will soon be published.

Marie (1941, p. 188) recorded *B. decorata* from the *B. mucronata* Zone of the Paris Basin. I have also found abundant specimens of *B. decorata* in the upper *B. mucronata* Zone at Meudon, on the outskirts of Paris. These specimens are 10 to 15 per cent larger than the average from England, but are very similar in all other characteristics.

I have found specimens of *B. decorata* in an advanced stage of development in material from R. K. Olsson's (1964, p. 160) locality NJK 134 in the Marshalltown Formation of New Jersey. Olsson (op. cit., p. 163) recorded *Globotruncana calcarata* Cushman, usually regarded as a reliable index fossil to the Upper Campanian, from this same locality.

Bolivinoides miliaris Hiltermann and Koch

Plate 35, figs. 4, 5

Bolivinoides draco (Marsson) *miliaris* Hiltermann and Koch 1950, pp. 604–6, text-figs. 2–4, nos. 32–34 (?), 39–41, 46–48; text-fig. 5, nos. 39*a–c*.

Bolivinoides draco miliaris Hiltermann and Koch; Reiss 1954, p. 155, pl. 28, figs. 9–12, 14.

Bolivinoides draco miliaris Hiltermann and Koch; Pożaryska 1954, p. 254, text-fig. 4.

Bolivinoides miliaris Hiltermann and Koch; Hofker 1957, p. 267, text-fig. 322*b*.

Bolivinoides draco miliaris Hiltermann and Koch; Bieda 1958, pp. 44, 45, figs. 14*a–c*.

Bolivinoides draco miliaris Hiltermann and Koch; Hiltermann and Koch 1960, p. 72.

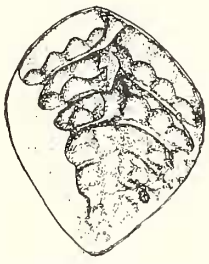
Bolivinoides miliaris Hiltermann and Koch; Vassilenko 1961, pp. 200, 201, pl. 40, figs. 4*a–c*, pl. 41, figs. 1*a–c*.

Bolivinoides draco miliaris Hiltermann and Koch; Hiltermann and Koch 1962, p. 317, table 19, pl. 46, fig. 9.

Bolivinoides draco miliaris Hiltermann and Koch; Hiltermann 1963, p. 222, pl. 4, figs. 21–23.
Bolivinoides draco miliaris Hiltermann and Koch; van Hinte 1963, pp. 106, 107, pl. 13, figs. 7, 8.

Remarks. B. miliaris is morphologically similar to *B. decorata* (Jones) in many respects and appears to have been derived from the latter during the late *B. mucronata* Zone (uppermost Campanian). *B. miliaris* can be distinguished from *B. decorata* by having a smaller length/breadth ratio. Its lateral outline is more rhomboidal than the more elongate, pear-shaped outline of *B. decorata*; the maximum breadth of *B. miliaris* is nearer the mid point of test, whereas the maximum breadth of *B. decorata* is closer to the apertural end. The ornamentation on *B. miliaris* is usually less regular than that of *B. decorata* and often, on the earliest 30 to 50 per cent of the test, the ornamentation consists of small knobs. The earliest 1 to 3 pairs of chambers of *B. decorata* are ornamented by less distinct lobes or knobs, or more often, these early chambers have a smooth surface.

B. miliaris differs from *B. australis* Edgell by having fewer ornamental lobes on its final chambers. *B. miliaris* usually has 4 and sometimes 5, whereas *B. australis* has 5 to 7 on its latest chambers. *B. miliaris* has a smaller size and usually has a more rhomboidal outline, although variants of *B. australis* sometimes possess a similar rhomboidal outline.



TEXT-FIG. 8. Bisected specimen of *Bolivinoides draco* (Marsson) showing tooth plate structure and internalsemi-conical bulges along base of chambers, corresponding to depressed areas between lobes on external surface.

B. miliaris gave rise to *B. draco* (Marsson) during the upper part of the Lower Maestrichtian. The earliest 50 to 60 per cent of the test of *B. draco* is more flaring than that of *B. miliaris*, which has a less angular outline. *B. draco* also has two very distinctive, well-developed, parallel medial ribs, which are produced by the fusing of the inner 'ornamental' lobes. Hiltermann and Koch (1960, p. 73) listed the stratigraphic range of *B. draco* in north-west Europe as the upper part of the Lower Maestrichtian to the top of the Maestrichtian. I have observed the same range for this species in western Europe and North Africa; however, I have not found *B. draco* in the British Isles. McGugan (1957, pl. 32, fig. 17) illustrated a specimen from the Ballycastle Pellet Chalk of Northern Ireland which he referred to *B. draco draco* Hiltermann and Koch. It is poorly preserved and there is some doubt as to whether this specimen should be considered *B. draco* (*s.s.*). Curry (1962, p. 180) also recorded a single specimen which he referred to *Bolivinoides* cf. *draco* from a submarine core from the English Channel.

Occurrence. Rare specimens of *B. miliaris* were found in the Ballycastle Pellet Chalk along the west side of Ballycastle Harbour, Northern Ireland. Curry (1962, p. 182, 184) recorded *B. miliaris* from two submarine cores which were obtained from an area in the English Channel halfway between the Isle of Wight and Cherbourg. The Upper Cretaceous fauna of the Ballycastle Pellet Chalk, which consists of a mixture of late Campanian and early Maestrichtian foraminifera, appears to be a derived fauna (see remarks under *B. decorata*) and therefore the age of these specimens is not precisely known.

The holotype of *B. miliaris* is from a bore hole near Niemburg, north-west Germany, and is from the *B. mucronata* Zone. Hiltermann (1963, p. 205) and Hiltermann and Koch (1960, p. 72) listed the range of *B. miliaris* in north-west Europe as uppermost Campanian and Lower Maestrichtian.

Bolivinoides pustulata Reiss

Plate 37, figs. 4*a*, *b*

Bolivinoides pustulata Reiss 1954, p. 156, pl. 29, figs. 9, 10.
Bolivinoides granulata Hofker 1957, pp. 250, 251, text-figs. 303, 310.
Bolivinoides pustulata Reiss; Hiltermann 1963, p. 214, pl. 2, fig. 17.
Bolivinoides granulata Hofker; Hiltermann 1963, p. 213, pl. 2, figs. 5, 11, 12.

Remarks. Topotypic specimens of *B. pustulata* have been compared with specimens from southern England and they appear to be conspecific. *B. pustulata* is closely related to *B. hiltermanni* (see p. 231) and it is suggested that the latter is the ancestral species. It has a much greater stratigraphic range than *B. pustulata*, which is restricted to the upper part of the *A. quadratus* Zone.

B. pustulata appears to be the direct ancestor of *B. praelaevigata* sp. nov., which is distinguished from it by its smaller, more compressed, more gradually tapering test. The ornamentation of *B. praelaevigata* is also more weakly developed and even more restricted to the medial portion of the test than that of *B. pustulata*.

B. pustulata is morphologically very similar to *B. granulata* Hofker and the latter is tentatively regarded as a junior synonym of *B. pustulata*. Unfortunately, however, the original illustrations given by Hofker (1957, text-figs. 303–10) do not allow a very exact comparison of all features and I have been unable to examine type material of *B. granulata*. Final judgement on this point must be withheld until type material can be studied.

EXPLANATION OF PLATE 37

All illustrations shaded camera lucida drawings, ×140. *a* = side view; *b* = terminal view.

Figs. 1–3. *Bolivinoides hiltermanni* sp. nov. Lower Campanian, *Actinocamax quadratus* Zone, Culver Cliff, Isle of Wight. 1, Holotype, Sample C29, BM P45724. 2, Paratype, Sample C24. 3, Paratype, Sample C29, BM P45725.

Fig. 4. *Bolivinoides pustulata* Reiss. Lower Campanian, *A. quadratus* Zone, Culver Cliff, Isle of Wight; Sample 23, BM P45741.

Fig. 5. *Bolivinoides* aff. *B. hiltermanni* sp. nov. Transitional form between *B. pustulata* and *B. hiltermanni*. Lower Campanian, *A. quadratus* Zone, Culver Cliff, Isle of Wight; Sample C23, BM P45728.

Fig. 6. *Bolivinoides sidestrandensis* sp. nov. Paratype, BM P45745. Lower Maestrichtian, *Belemnitella lanceolata* Zone, Sidestrand, Norfolk.

Figs. 7–9. *Bolivinoides strigillata* (Chapman). Topotypes. Santonian, *M. testudinarius* Zone, Phosphatic Chalk, Taplow, Buckinghamshire. Specimens 7 and 8 are also illustrated by unretouched photographs on Plate 34. 7, BM P45729; 8, BM P45730; 9, BM P45731.

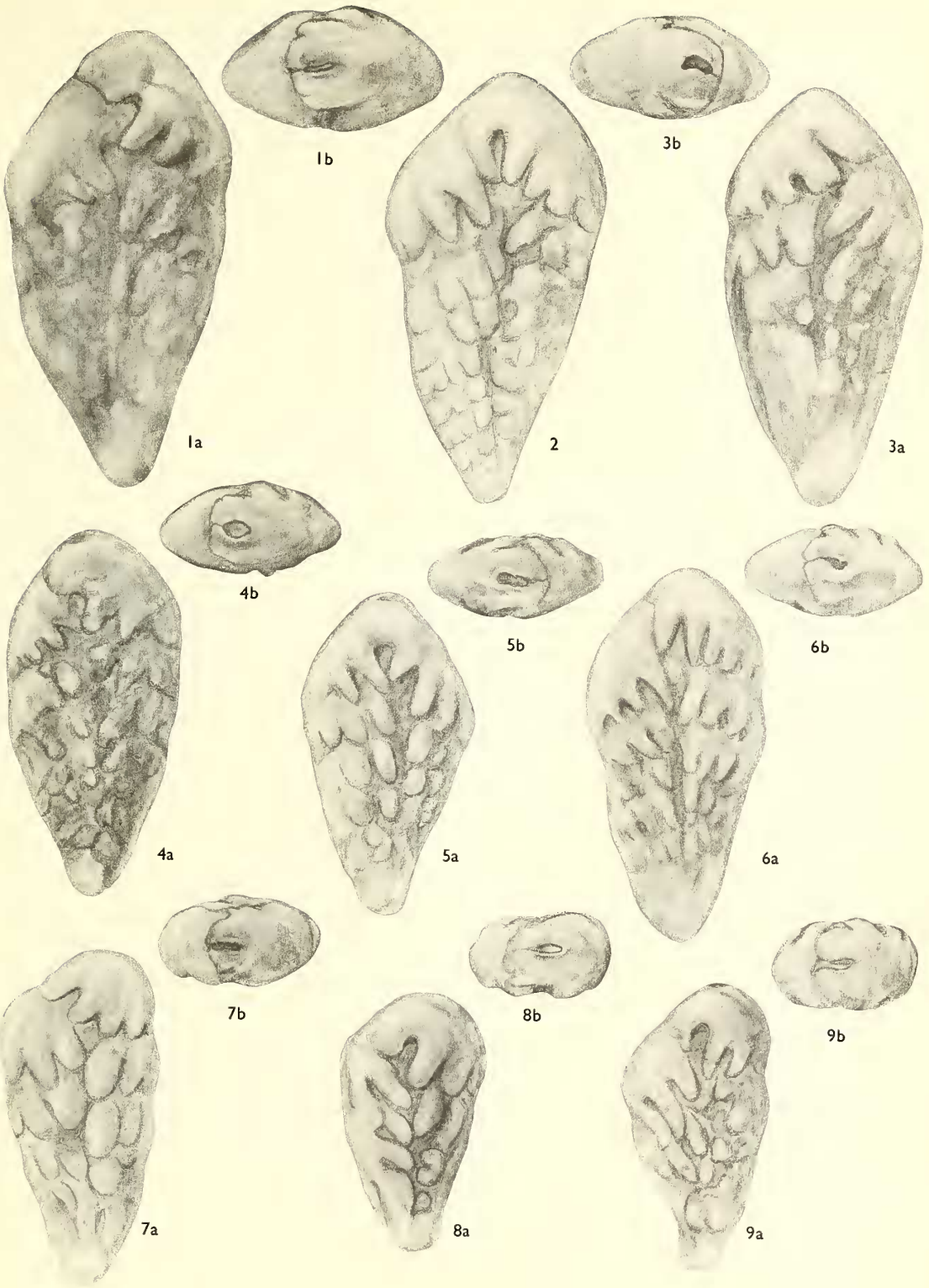
EXPLANATION OF PLATE 38

All illustrations shaded camera lucida drawings, ×140. *a* = side view; *b* = terminal view.

Figs. 1–5. *Bolivinoides laevigata* Marie. Series of specimens showing variation in test shape and ornamentation. 1, 5, Lower Maestrichtian, *B. lanceolata* Zone, Sidestrand, Norfolk. 2–4, Upper Campanian, *B. mucronata* Zone, Culver Cliff, Isle of Wight, Sample C10. 1, BM P45735; 2, BM P45736; 3, BM P45737; 4, BM P45738; 5, BM P45739.

Fig. 6. *Bolivinoides peterssoni* Brotzen. Final chamber broken. Lower Maestrichtian, *B. lanceolata* Zone, Sidestrand, Norfolk; BM P45742.

Figs. 7–9. *Bolivinoides praelaevigata* sp. nov. Lower part of Upper Campanian, *B. mucronata* Zone, Culver Cliff, Isle of Wight. 7, Holotype, Sample C13, BM P45732; 8, Paratype, Sample C13, BM P45734; 9, Paratype, Sample C18, BM P45733.



BARR, Upper Cretaceous *Bolivinoides*